C-Band Polarimetric Backscatter Observations of Great Lakes Ice

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Abstract – Two experiments were carried out during the 1997 winter season across the Straits of Mackinac and Lake Superior. C-band radar backscatter signatures of various ice types and open water were measured from U.S. Coast Guard Ice Breaker vessels together with ground truth data. Polarimetric backscatter data were obtained at incident angles up to 60° for all polarizations. Backscatter signatures of 20 ice types/conditions were collected along the Coast Guard ship tracks in February and March 1997. The backscatter data set with in-situ ice characteristic parameter measurements are to be used in the development of the ice mapping algorithms using satellite SAR data over the Great Lakes. The results at C-band frequency for multiple incident angles and multiple polarizations are applicable to the current ERS and RADARSAT Synthetic Aperture Radars (SAR) and the future ENVISAT SAR.

INTRODUCTION

Ice cover in the Great Lakes, the most obvious seasonal transformation in the physical characteristics of the lakes, has a major impact on the regional climate, local commerce, and public safety [1]. Extending the winter navigation season can save millions of dollars in coal and ore shipping [2]. To the hydropower industry, ice is potentially harmful to the installations on the Niagara River [1]. The number of days that ice cover exceeded 40% is an important input parameter to a whitefish recruitment forecast model in Lake Michigan [3]. Ice cover duration is predicted by several General Circulation Models to reduce significantly under the CO_2 doubling scenario. Winter ecology may be strongly affected by the ice cover reduction [4]. Ice jams not only impede navigation but also cause dangerous flooding [5].

Many practical applications such as winter navigation, shore structure protection, and ice control require high resolution ice mapping. These problems necessitate the remote sensing of the Great Lakes ice cover with spaceborne SAR for high resolutions, large coverages, and day-and-night operations [6]. Many present and future SARs such as ERS, RADARSAT, and ENVISAT operate at C band with different polarizations and incident angles. To interpret the satellite SAR data, a comprehensive data set of C-band backscatter signatures of different ice types/conditions over the Great Lakes need to be measured together with in-situ ice characterizations. For this purpose, the Jet Propulsion Laboratory (JPL) and the National Oceanic and Atmospheric Administration (NOAA) Great Lakes Environment Research Laboratory (GLERL) carried out the 1997 Great Lakes Winter Experiments with the participation of the U.S. Coast Guard.

The research by the Center for Space Microelectronics Technology, Jet Propulsion Laboratory, California Institute of Technology was sponsored by the National Oceanic and Atmospheric Administration (NOAA) through an agreement with the National Aeronautics and Space Administration. The research by the Great Lakes Environmental Research Laboratory is supported by NOAA.

THE 1997 GREAT LAKES WINTER EXPERIMENTS

We conducted two experiments during the 1997 winter season across the Straits of Mackinac and Lake Superior. The experimental campaign was coordinated into two expeditions on two different USCG Ice Breaker vessels, the Biscayne Bay in February and the Mackinaw (an Arctic-class ice breaker) in March.

In these experiments, the Jet Propulsion Laboratory (JPL) polarimetric scatterometer was mounted on board the Biscayne Bay and the Mackinaw to measure the backscatter. The scatterometer was operated at C-band with the full polarization capability and incident angles from 0° to 60°. Thus, the results are applicable not only to RADARSAT SAR with the horizontal polarization, but also with ERS SAR with the vertical polarization and the future ENVISAT SAR with dual polarizations.

A Global Positioning System (GPS) receiver unit was used to record the locations along the ship routes when the scatterometer data were taken. The GPS data were downloaded to the computer that controlled the radar in near-real time. The data were plotted out on a map of the Great Lakes to show the locations of the ice types where radar data were obtained. The computer internal clock was synchronized with the GPS time and both radar data and GPS data were time tagged so that they can be correlated. An anemometer was used near the radar to measure in-situ wind. The ship instruments also provided location, wind data, and temperature data.

During the experiments, accurate calibration measurements were conducted to calibrate the scatterometer data. A trihedral corner reflector of known radar cross section was used for this purpose. The corner reflector was aligned with the radar pointing direction with a laser pointer. Another calibration target, a metallic sphere, was used to obtain additional data to validate the radar calibration. During the experiment on board the Biscayne Bay, the calibration measurements were taken while the ship docked near De Tour Village in Michigan. In the Mackinaw experiment, the calibration targets were setup on an open area at the back of the ship and microwave absorbers were used to avoid unwanted signals from reflections and multipath effects.

Ice truth data for different ice types were obtained. Ice thickness and snow thickness were measured. Photographs showing the layering structure of snow ice and lake ice with different amount of air inclusions were taken. Wind speed and temperature were recorded. We also took a number of snow thickness measurements over an area at a location during the Biscayne Bay experiment to determine the range of snow thickness distribution. Photographs were taken to estimate the surface roughness condition and snow coverage. For each set of radar measurements, photographs were taken both in the near range coincident to the area of the radar footprint and in the far range for an overall picture of the ice type.

BACKSCATTER MEASUREMENT RESULTS

We collected approximately 2000 radar data files for various ice types. For each ice type, we obtained radar data from 0° to 60° incident angles. For each incident angles, the measurements covered several different samples in azimuth directions scanned over the targeted area. For each antenna look direction, data were coherently averaged by 20 times over 401 samples in the frequency domain with 1 GHz bandwidth. The data included both magnitudes and phases of the scattering matrix for all combinations in the linear polarization basis. The data are processed and calibrated into polarimetric backscattering coefficients.

We acquired backscatter signatures of various ice types with different physical condition, feature scale, thickness, snow cover, and concentration. Some of the ice types are pancake ice with complicated structures, finely crushed ice refrozen into a matrix of lake ice with a very thin snow cover, and plate ice with angular polygon shape with a larger scale compared to the rounded pancake ice. A typical ice type over the Great Lakes is snow ice (white ice) over lake ice (black ice) with various thickness. We encountered a number of rubble ice fields produced by strong wind and wave actions which broke and pushed the ice together. Broken layers of ice, whose total thickness reached several meters, were seen in this highly deformed ice type. New black ice of a few inch thick was transparent (almost no bubble) with very smooth upper and lower surfaces. Snow cover from a dusting condition to a thick layer was observed.

An example for polarimetric backscatter signatures of pancake ice is presented in Fig. 1. This ice type consists of of broken pieces of ice with rounded shape and a raised rim around the edge caused by wind and wave actions. Fig. 1 shows that backscatter σ_{vv} decreases quickly with incident angle, the copolarized ratio $\gamma = \sigma_{vv}/\sigma_{hh}$ is negative or close to zero, the crosspolarized ratio $e = \sigma_{hv}/\sigma_{hh}$ is small at large incident angles, and the correlation coefficient ρ between the horizontal and vertical is small at large incident angles.

Measured backscatter data of typical snow covered lake ice indicate that the horizontal backscatter is larger than the vertical backscatter especially at larger incident angles. This backscatter property of lake ice is different from that of most sea ice types whose vertical return is usually larger than the horizontal one. For future ENVISAT SAR data with both polarizations, this result is useful to distinguish the fresh water ice from open water, which has $\sigma_{vv} > \sigma_{hh}$. Radar data of the typical lake ice type taken in March along the ship track show that C-band waves can propagate more than 1 m in the ice. For deformed ice in a rubble field, the backscatter is very strong across the range of incident angles. Black ice with a thin snow cover has low backscatter with a strong decreasing gradient in incident angle. The polarimetric scatterometer data set is useful for the development of the Great Lakes ice mapping algorithm. Furthermore, this data set can be used to determine which ice type can be observed for a given set of operating parameters of a satellite SAR, such as the system noise floor, polarizations, and incident angles.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the Captains and Crews of the USCG Mackinaw and the USCG Biscayne Bay Ice Breakers, without whom the experiments were not possible. The USCG Traverse City Air Station help in ice survey and personnel transportation on helicopter, and the assistance from the USCG Ground Station at Portage and the Houghton Memorial Airport in the experiments are appreciated.

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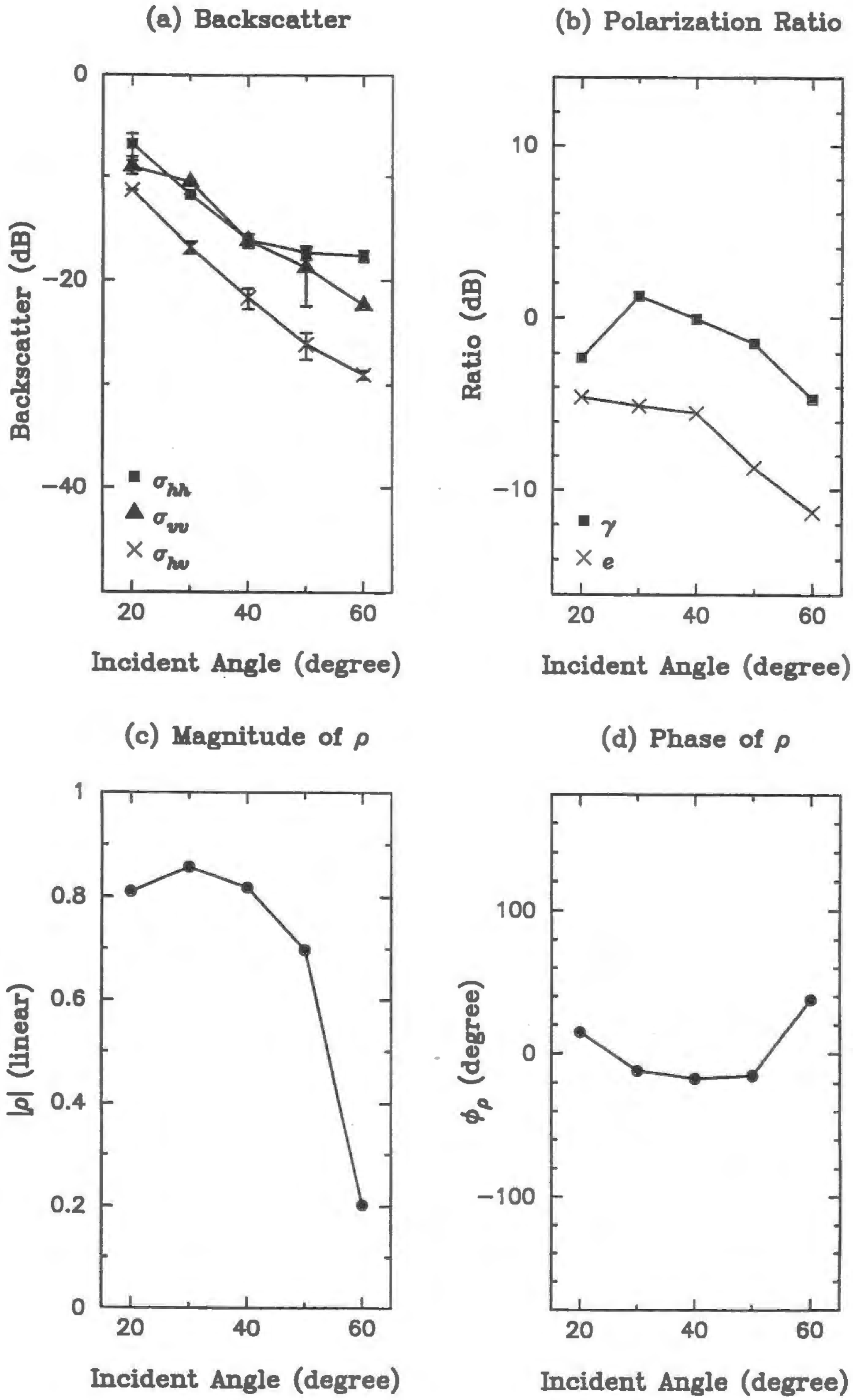

Figure 1. Polarimetric backscatter of pancake ice: (a) backscattering coefficients, (b) polarization ratios $\gamma = \sigma_{vv}/\sigma_{hh}$ and $e = \sigma_{hv}/\sigma_{hh}$, (c) magnitude of the complex correlation coefficient ρ between horizontal and vertical returns, and (d) phase of ρ.

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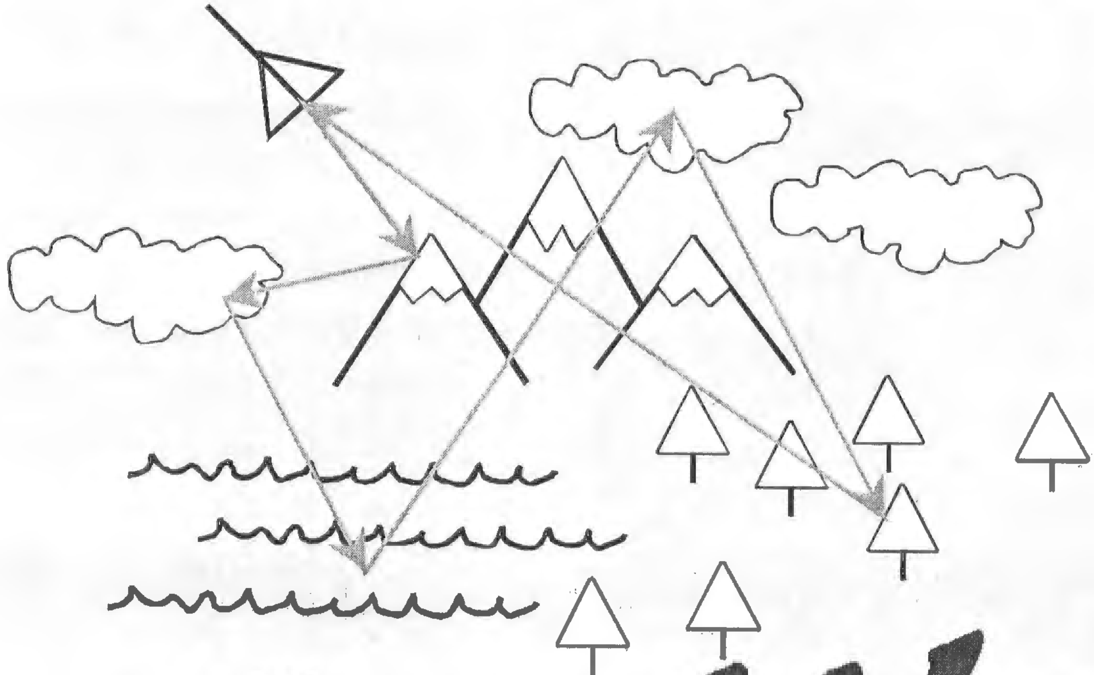

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